NAVORD REPORT 2460

LOW VELOCITY DETONATION OF CERTAIN PRIMARY EXPLOSIVES

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U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

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ABSTRACT: The nature of the damage sustained by tubes in which the explosives were confined indicated that both lead azide and mercury fulminate, when pressed to rather high densities, reacted in a very different manner than when loaded at slightly lower densities. It was found that this different type of reaction was induced by initiation within a limited range of vigor. Measurements of propagation velocity gave three ranges for mercury fulminate 4,000 to 5,000 meters per second, 1,400 to 1,700 meters per second and a few inches per second. Only the two upper ranges were observed for lead azide. More vigorous initiation resulted in a greater tendency toward reactions in the higher velocity ranges. Further observations of the intermediate, 1,400 to 1,700 meters per second, velocity range of mercury fulminate showed no difference between the velocities obtained with 0".1 and 0".15 diameter columns nor did the velocity vary when measured over 1, 2, and 3 inch column lengths. An attempt to induce a reaction of this type in 0".2 diameter columns resulted only in reactions which propagated at velocities in the high range of 4,000 to 5,000 meters per second. Experiments with various confining media seemed to show some effect of confinement but the results were too scattered to be statistically significant. Several possible mechanisms of the reaction are discussed.

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This report is a discussion of a phenomenon which was first incidentally observed in the course of other experiments. Because an understanding of this phenomenon might be expected to contribute to the understanding of the initiation of detonation, further studies were made under Task Assignment NOL-Re2c-1-1(EP)-52. Most of the experimental work reported herein was done by L. E. Starr and C. W. Goode. The observations which have been made up to the present are preliminary in nature, but seem to be quite convincing evidence of the existence of an unusual phenomenon. The material reported herein was presented at a meeting of the American Physical Society in Washington, D. C., on 3 May 1952. The present report is for information only and is not meant as the basis for action.

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LOW VELOCITY DETONATION OF CERTAIN PRIMARY EXPLOSIVES

Introduction

Stable low velocity detonation of liquid explosives in small sections has been observed by many investigators. Mulcahy and Vines, reference (a), for example report that nitroglycerine in 0.5 mm film detonated at a rate of 1,800 meters per second while in 0.15 mm and thicker films it detonates at over 5,000 meters per second. Chantor and Ratner, reference (b), report similar results for nitroglycerine and nitroglycol. Low velocity reactions of solid explosives, both primary and high explosives, have also been observed frequently, but generally as a transient phenomenon associated with the growth or decay of detonation.

The observations reported herein are of apparently stable reactions of lead azide and mercury fulminate which propagate at velocities of the order of one third of that for high order detonation of these materials.

In the course of some studies of the growth of detonation, it was observed that the effects of the explosions of both lead azide* and mercury fulminate upon the containers in which they were loaded changed abruptly when they were loaded at pressures such that the interstitial voids accounted for less than six or seven percent of the volume. In these experiments, the explosives were loaded into very heavy walled brass tubes, Figure (1), made by drilling and reaming 0.150 diameter holes centrally in one inch bar stock. The tubes were counterbored at one end to receive electric initiators. The tubes were loaded by increments not more than one diameter in length to keep variations of density within bounds. The electric initiators used were of special design allowing for the use of carefully measured quantities of the initiating explosive, eighteen milligrams of lead styphnate. After firing, the tubes were sectioned and observations made of the variations in the diameter of the hole with length. Figures (2), and (3) are photographs of typical groups of specimens. Note that the diameters of the holes increase with loading density and then abruptly decrease when the percentage voids is reduced to less

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*Dextrinated lead azide was used in all of these experiments.

than six or seven percent. The conical fracture, discussed by Starr and Savitt, reference (c), also is absent in the high density specimens. It is also apparent in the photograph that the interior of the holes in the specimens which had been loaded to high densities is bright rather than dark colored as in the lower density specimens. Although it can not be seen in the photograph, the specimens which had been loaded at the lower densities had numerous longitudinal cracks, apparently having failed in tension due to the outward momentum of the wall material, after the internal pressure had reduced. In contrast, the specimens which had been loaded at the higher density, had very smooth, gently rippled interiors as if they had failed from static pressure. The mercury or lead resulting from the reaction of the lead azide or mercury fulminate respectively was deposited in a bright, nearly mirror like film, whereas the deposits in the holes which had been loaded at high density were dull black. Figures (4) and (5), are superimposed shadowgraph tracings of the cross sections of holes resulting from charges loaded at several densities. Note that the enlargement of the holes resulting from the action of the high density explosive is intermediate between that caused by the low density explosive and that caused by the explosive of intermediate density.

Propagation Velocity Measurements

The observations discussed above left little doubt that the reaction of the highly compressed explosive is unlike that of the less dense material. One characteristic of such a process which can be readily measured, is the velocity with which it propagates. The arrangement of the explosive for propagation rate measurements is shown in Figure (6). The explosive columns were quite similar to those used in the experiments mentioned above, except that they, and the tubes in which they were confined, were made in three sections so that a start and a stop probe could be inserted. The ionized conductive gases of the reaction front were used to generate a "start" and a "stop" signal to start and stop a Potter counter chronograph. Except for the time measurement apparatus, the technique was similar to that discussed in reference (d). Propagation velocity loading density data obtained in this manner are plotted in Figures (7) and (8). Note that the detonation velocities of both lead azide and mercury fulminate approach 5,000 meters per second at their crystal densities, but that both materials also have propagation rates in the neighborhood of 1,500 meters per second at high densities.

Further experimentation showed that the type of reaction which occurs is dependent upon the vigor of initiation. If, in the arrangements shown in Figures (1) and (6), mercury fulminate loaded at 60,000 psi is initiated by means of a flash charge of fifty milligrams of lead styphnate or as little as five milligrams of loosely packed lead azide, it detonates at the high rate, about 4,500 meters per second. If the same material is initiated by means of eighteen milligrams of lead styphnate, it will probably propagate at about 1,400 to 1,700 meters per second and if it is initiated by as little as five milligrams of lead styphnate it is more likely to burn at a rate of a few centimeters per second. The rate of the most probable reaction increases with the vigor of initiation. Lead azide has more tendency to detonate at its high rate and has not been observed to react at a propagation rate less than a thousand meters per second in these experiments.

Although the low velocity detonation is somewhat variable in velocity, no significant difference was noted between the velocities measured over distances of one, two and three inches. Mercury fulminate, pressed at 60,000 psi reacted with a propagation rate of 1,510 to 1,700 meters per second in 0".10 diameter columns and 1,580 to 1,720 meters per second in 0".150 diameter columns. In the same set of experiments and under as nearly identical conditions as possible 0".20 diameter columns of mercury fulminate detonated at between 4,150 and 5,220 meters per second. Five shots were fired in each of the above experiments. One specimen each of the 0".15 and 0".2 diameter columns burned at a rate of a few inches per second.

One tenth inch diameter columns of mercury fulminate loaded at 80,000 psi in steel, copper and aluminum gave the following results:

Table 1

Propagation Velocity in Meters Per Second vs Confinement
(Densely Packed Mercury Fulminate)

Steel	Copper	Aluminum
1780	1515	5130
1640	1280	1170
1460	1410	1170
1640	1410	1575
1780	1460	----

Although these results might be said to give some indication of a trend, the differences are not statistically significant.

Discussion

Three possible mechanisms have been suggested for reaction described above. (1) The expansion of the tube due to the pressure of the product gases is transmitted by the metal to sections where this pressure is not acting. The expansion of the tube ahead of the reaction zone exposes new peripheral surface of the explosive column over which the reaction propagates quite rapidly. This expansion would be transmitted at the velocity of a shear wave in the metal. The original experiments were with brass and copper in which materials transverse waves propagate at velocities in the same range as those mentioned above. The lack of correlation between velocity of propagation and the transverse wave velocities of the several other confining media used reduces the tenability of this hypothesis. (2) The reaction is a low velocity detonation of the type predicted by the curved front theory of Eyring et al., reference (e). This would be a true detonation in the sense that it is a shock propagated reaction. As pointed out by Eyring, et al., reference (e), and by Bowden, reference (f), reactions can be propagated by shocks of this intensity only through the formation of hot spots, since the energy available per unit volume in such shocks is sufficient to raise the temperature only a few degrees. The low detonation predicted by the curved front theory has an inverse diameter effect, i.e., larger diameter charges have lower low detonation velocities than smaller diameter charges. Some of the low velocity detonations in liquids display this effect. As noted above, the phenomenon discussed herein shows no evidence of such an effect. The experimental errors, of course, may be sufficient to conceal such effects. (3) The reaction is a high velocity burning reaction in which the pressure and hence the burning rate is limited by the yielding of the confining metal. Such high velocity burning might be predicted by an extension of the theory of growth of detonation in solid explosives, proposed by Andreev, reference (g). According to this theory, the increase or decrease of burning rate depends upon the relation between the rate at which gas is evolved by the reaction and that at which it can escape from the region in which the reaction takes place. If the rate of evolution is greater than the rate of escape the pressure and hence the propagation rate

will increase. Conversely if the rate of escape is greater the propagation rate will decrease. Thus, if in a given system the rate of evolution is greater than the rate of escape at all pressures above initial conditions, the reaction will accelerate until its propagation rate is limited by other factors. In most cases, the limit is determined by the density and compressibility of the explosive and products, and the reaction so limited is the normal detonation of the material. According to this view, the reactions discussed herein might occur when the yielding of the metal increases the effective escape rate to a value in excess of the rate of evolution. It is plain that such a reaction would be more or less stable. If this interpretation is correct there should be some correlation between the propagation rate of such materials and the strength of the materials in which they are confined. Table 1 shows some indication of such a correlation but the spread of the data is such that the differences in rates for the various confining media are not statistically significant.

Conclusions

From the foregoing it may be concluded that: (1) under certain conditions lead azide and mercury fulminate undergo progressive explosive decomposition with a propagation rate of 1,200 to 1,700 meters per second; (2) the probability of such a reaction occurring depends upon loading density, column diameter, vigor of initiation, and, probably, state of confinement. These conditions appear to be quite critical. This type of reaction was observed only in explosives loaded at a very high density in tubes 0.150 inside diameter and smaller; (3) it appears improbable that the reaction can be explained as a surface reaction related to the velocity of transverse waves in the confining medium. It may be either a low velocity detonation of the kind predicted by Eyring, et al., reference (e), or a high velocity deflagaration of the kind which might be predicted from the theory of Andreev, reference (g).

R. F. STRESAU

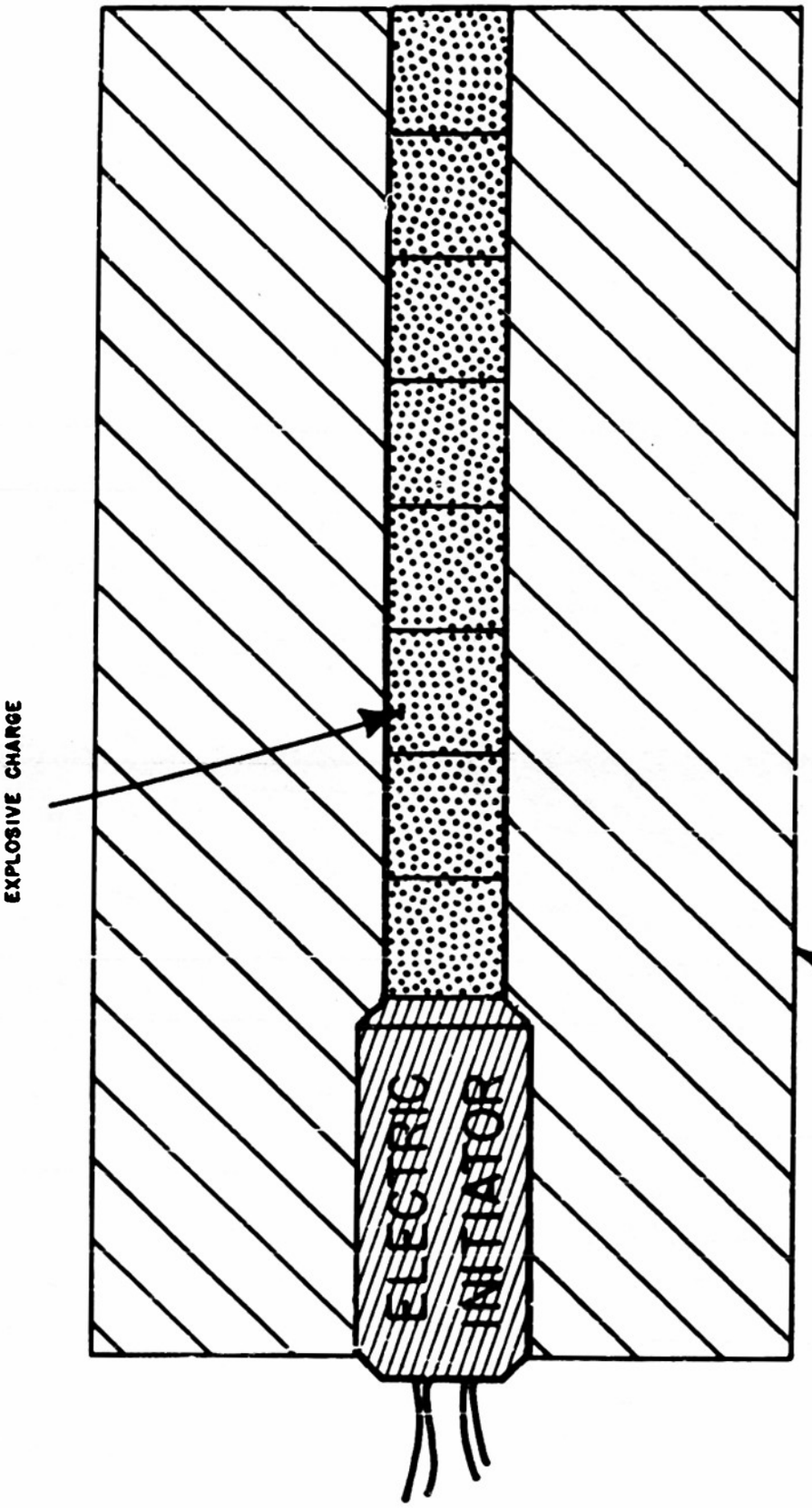


FIG. 1

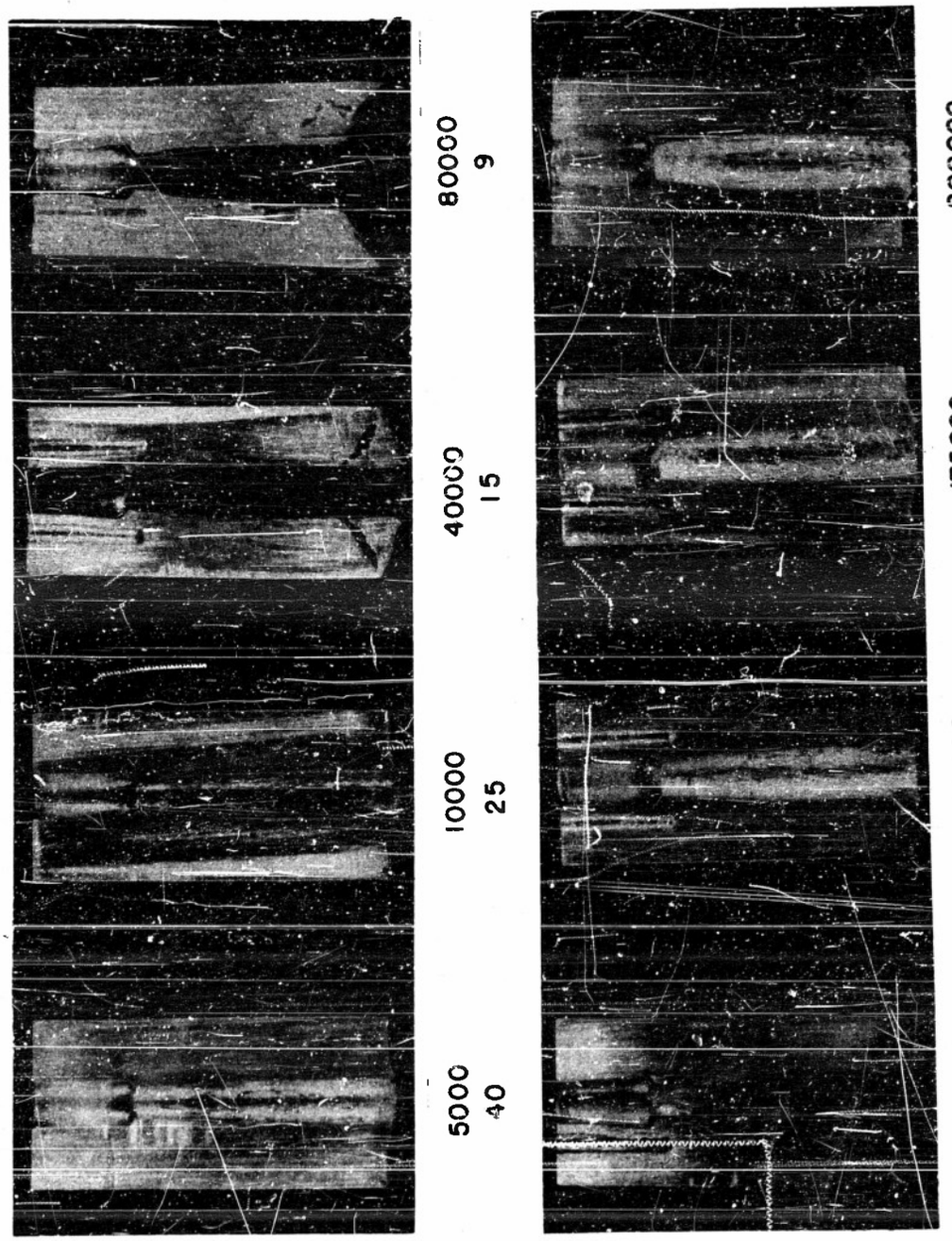
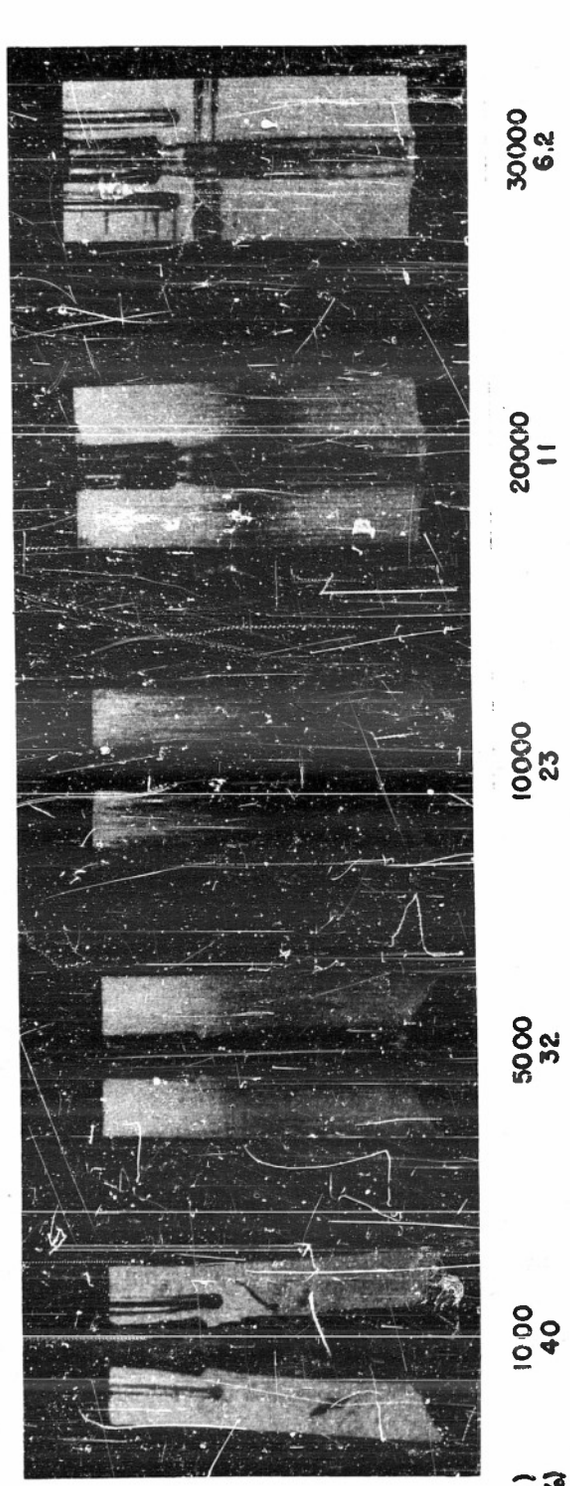

LDG. (PSI)
VOIDS (%)
5000
40
10000
25
40000
15
80000
9
LDG.(PSI)
VOIDS (%)
100 000
7
130000
5.4
175000
4.6
200000
4.2

FIG. 2


LDG. (PSI)
VOIDS (%)
1000
40
5000
32
10000
23
20000
11
30000
6.2

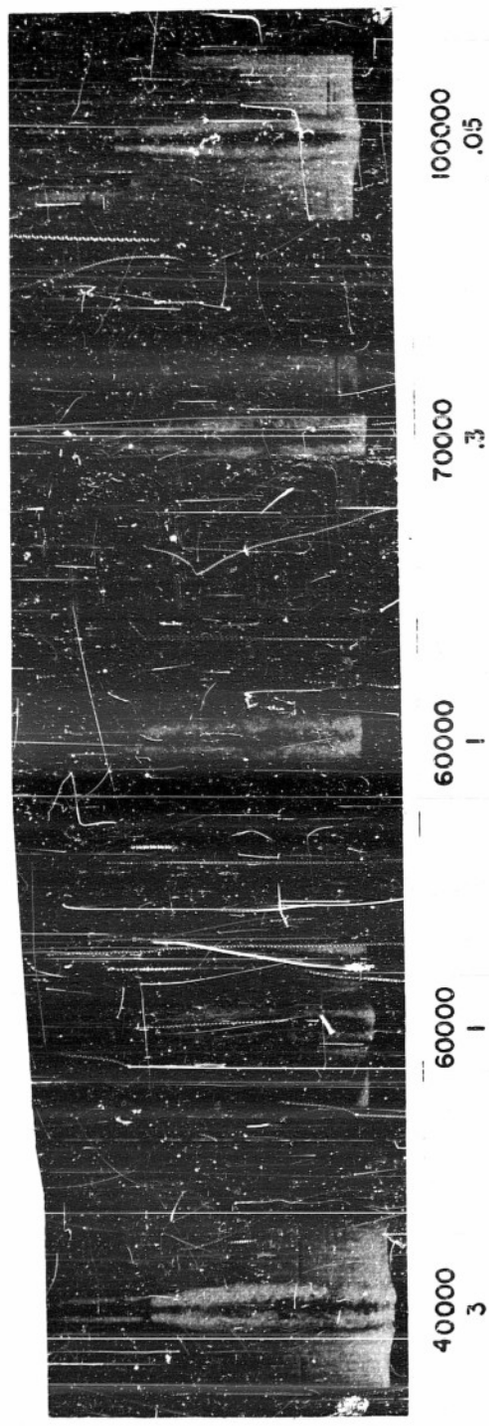

LDG. (PSI)
VOIDS (%)
40000
3
60000
1
60000
1
70000
.3
100000
.05

FIG. 3

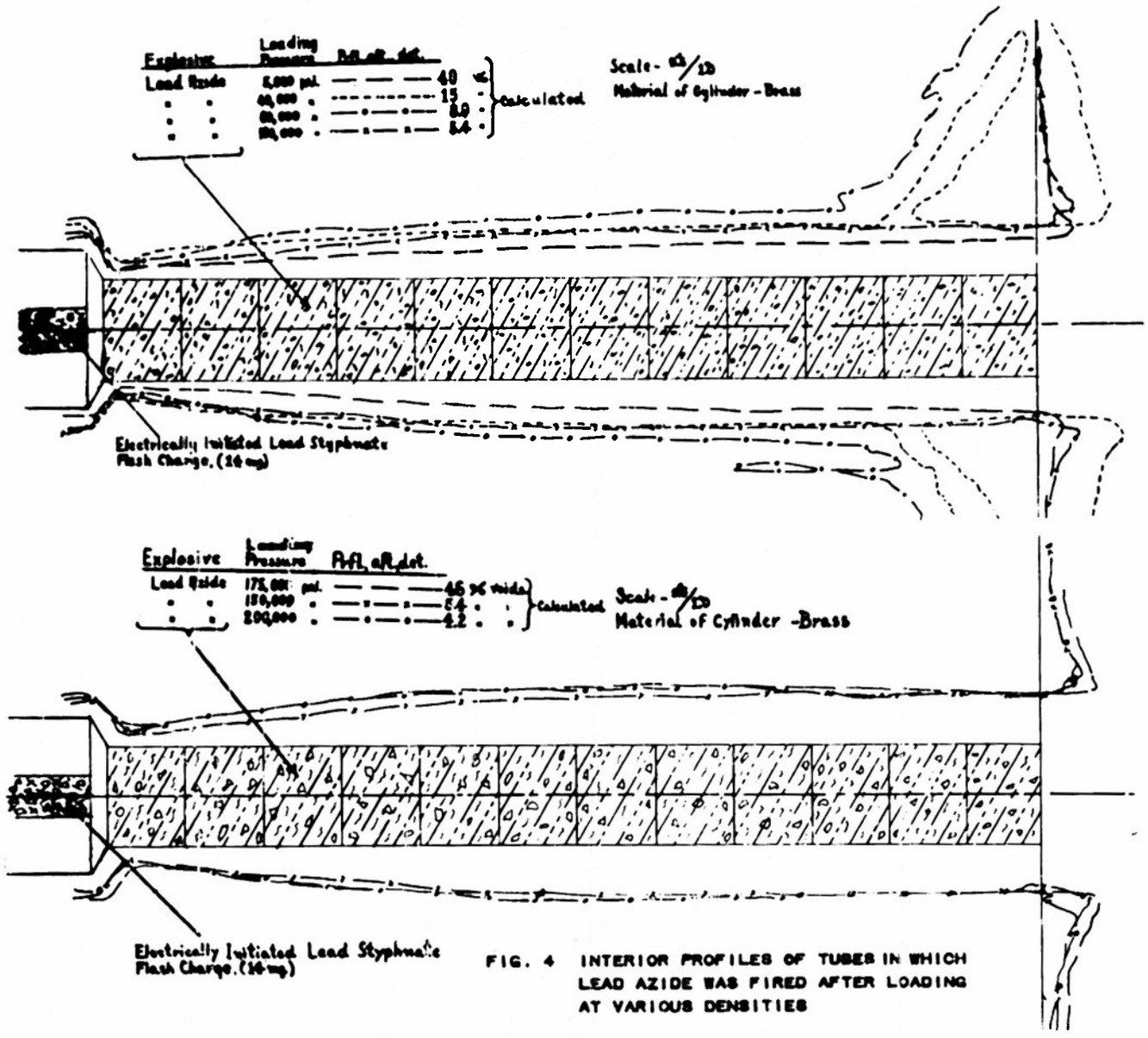


FIG. 4 INTERIOR PROFILES OF TUBES IN WHICH LEAD AZIDE WAS FIRED AFTER LOADING AT VARIOUS DENSITIES

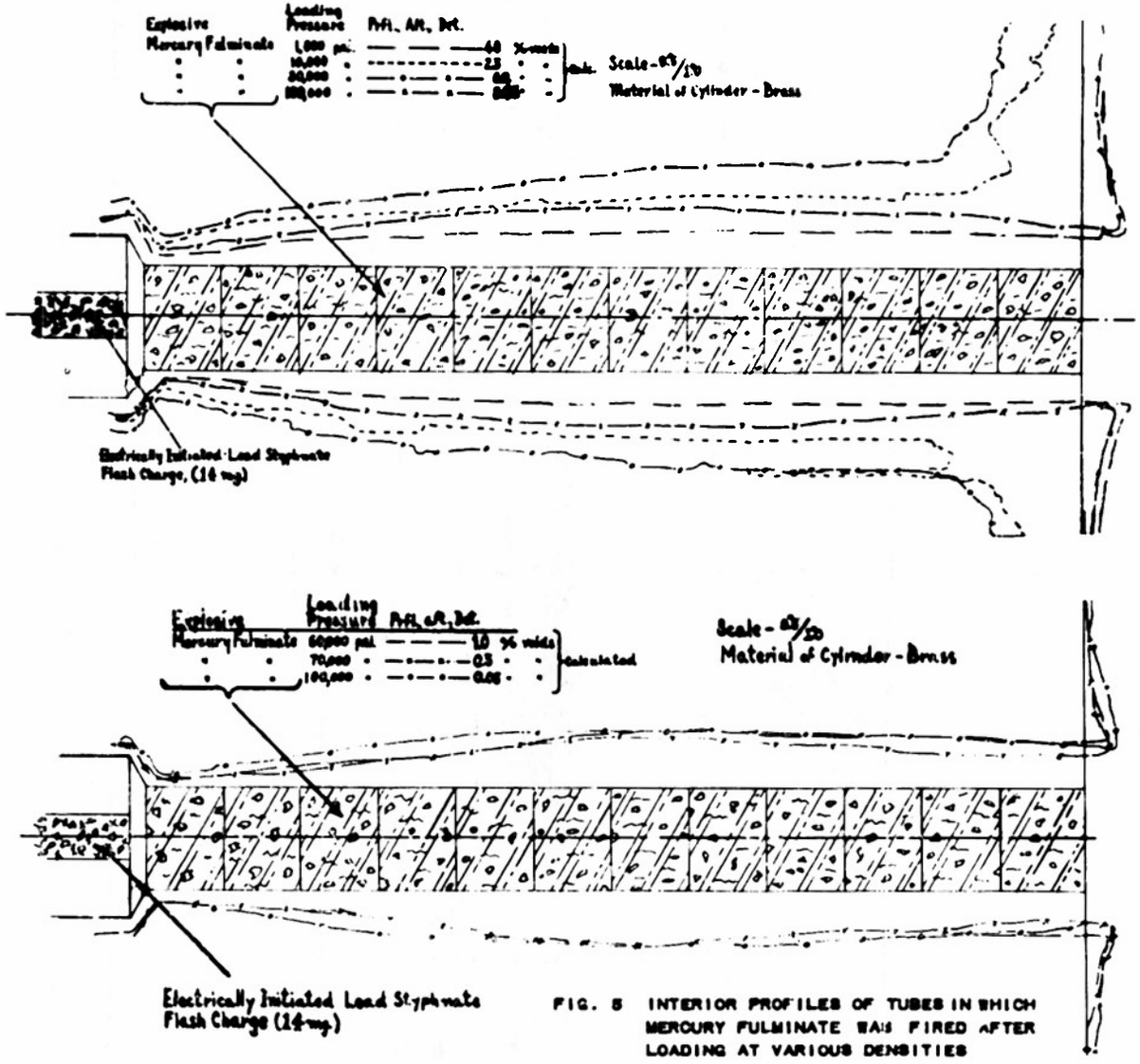


FIG. 5 INTERIOR PROFILES OF TUBES IN WHICH MERCURY FULMINATE WAS FIRED AFTER LOADING AT VARIOUS DENSITIES

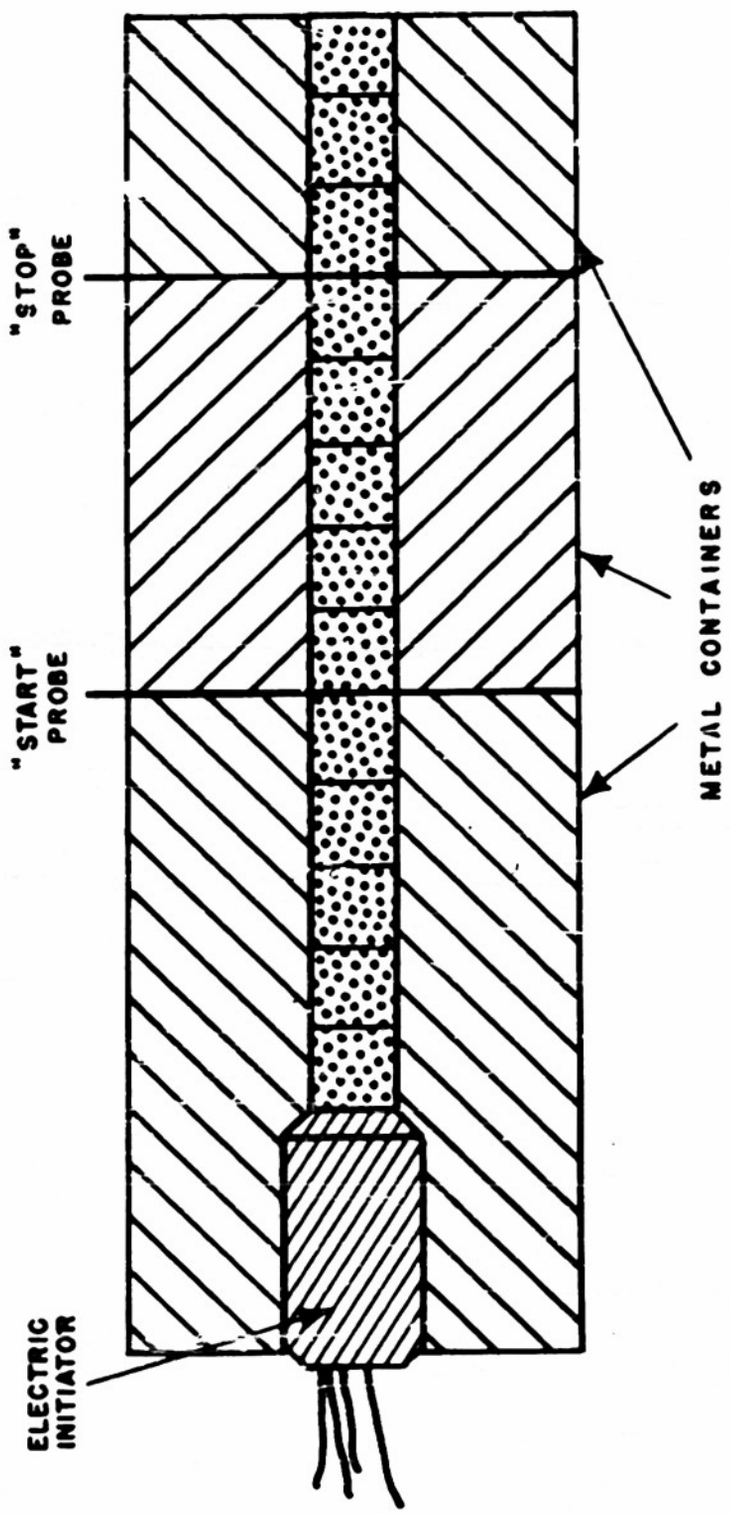

"STOP" PROBE
"START" PROBE
METAL CONTAINERS
ELECTRIC INITIATOR

FIG. 6

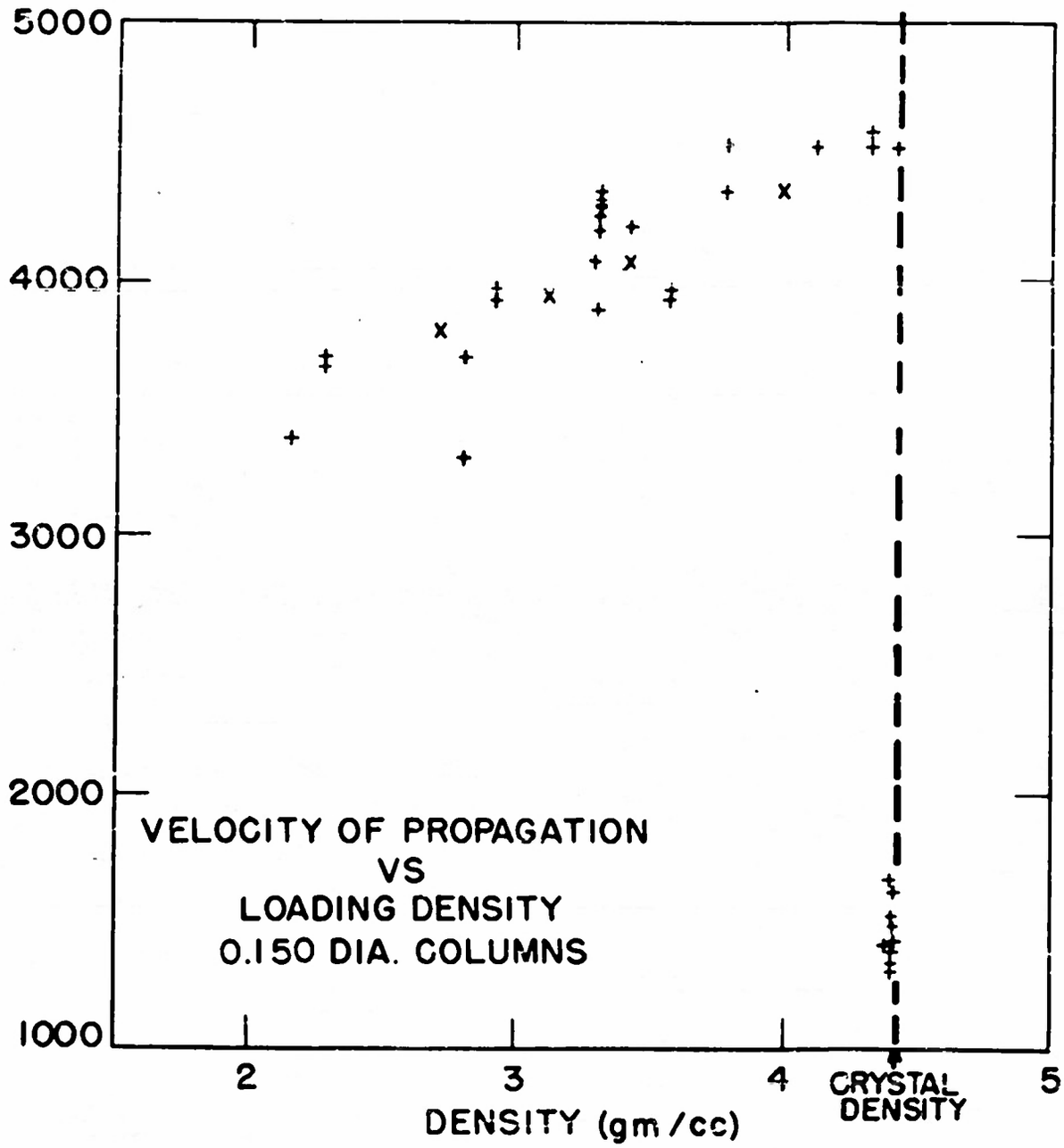


FIG. 7

EXPLOSIVE REACTIONS
OF
MERCURY FULMINATE

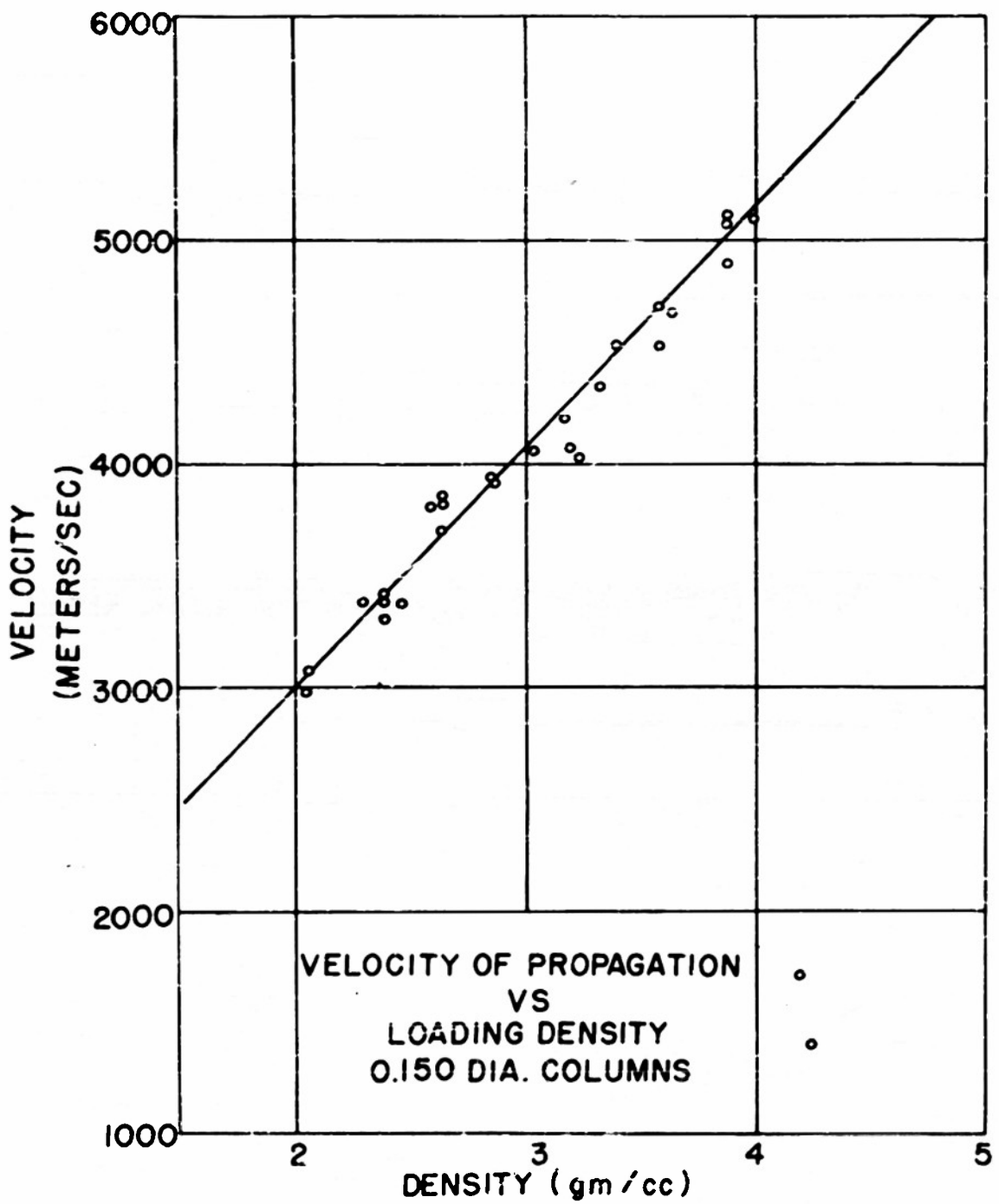


FIG. 8

EXPLOSIVE REACTIONS
OF
MERCURY FULMINATE

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